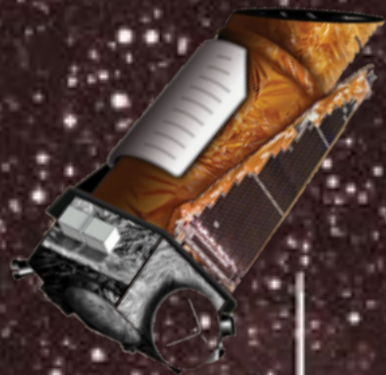




Chasing Shadows in the Night:

How NASA's Kepler and TESS Missions Are Revolutionizing Exoplanet Science



Jon M. Jenkins
NASA Ames Research Center

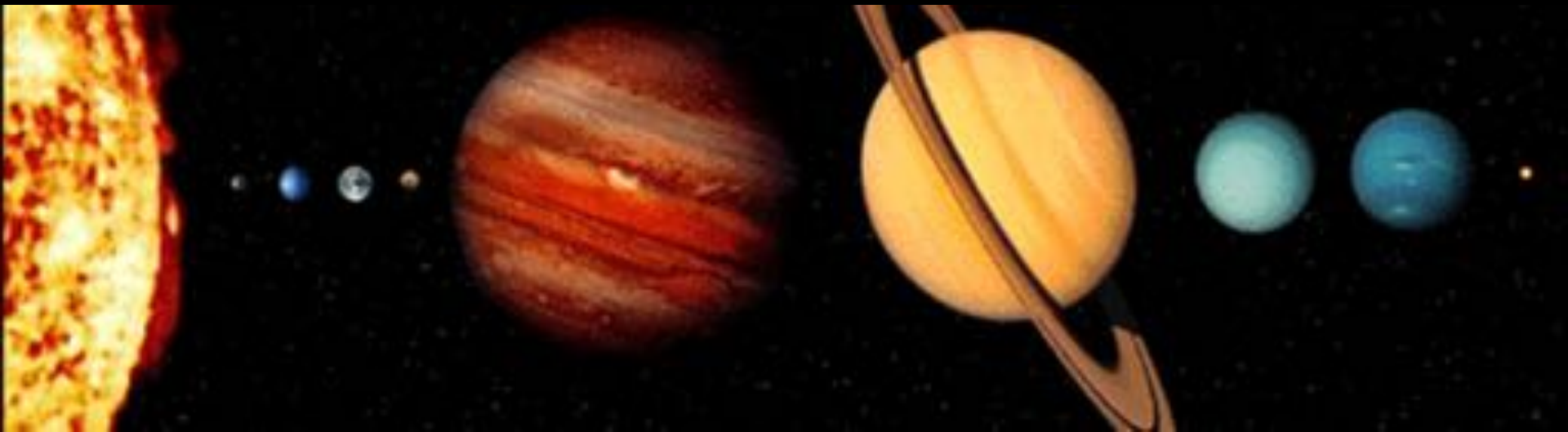


Friday October 15, 2021

Tri-Valley Star Gazers Astronomy Club



All the Known Planets In 1994



A More Recent Pictures of Planets (2012)



ALL 786 KNOWN PLANETS

(AS OF JUNE 2012)

TO SCALE

(SOME PLANET SIZES ESTIMATED BASED ON PROBS)



THIS IS OUR SOLAR SYSTEM.

THE REST OF THESE ORBIT OTHER STARS
AND WERE ONLY DISCOVERED RECENTLY.

MOST OF THEM ARE HUGE BECAUSE
THOSE ARE THE KIND WE LEARNED TO
DETECT FIRST, BUT NOW WE'RE FINDING THAT
SMALL ONES ARE ACTUALLY MORE COMMON.

WE KNOW NOTHING ABOUT WHAT'S ON ANY OF THEM

What Does Habitable Mean To You?

- Right temperature
- Air
- Liquid water
- Light
- Radiation shield
- Asteroid protection



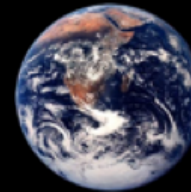
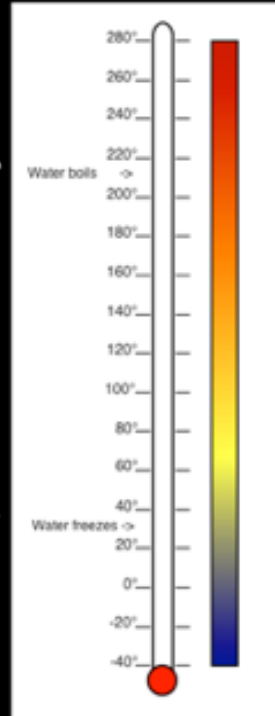
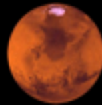
The Goldilocks Zone



Venus: Way too hot!

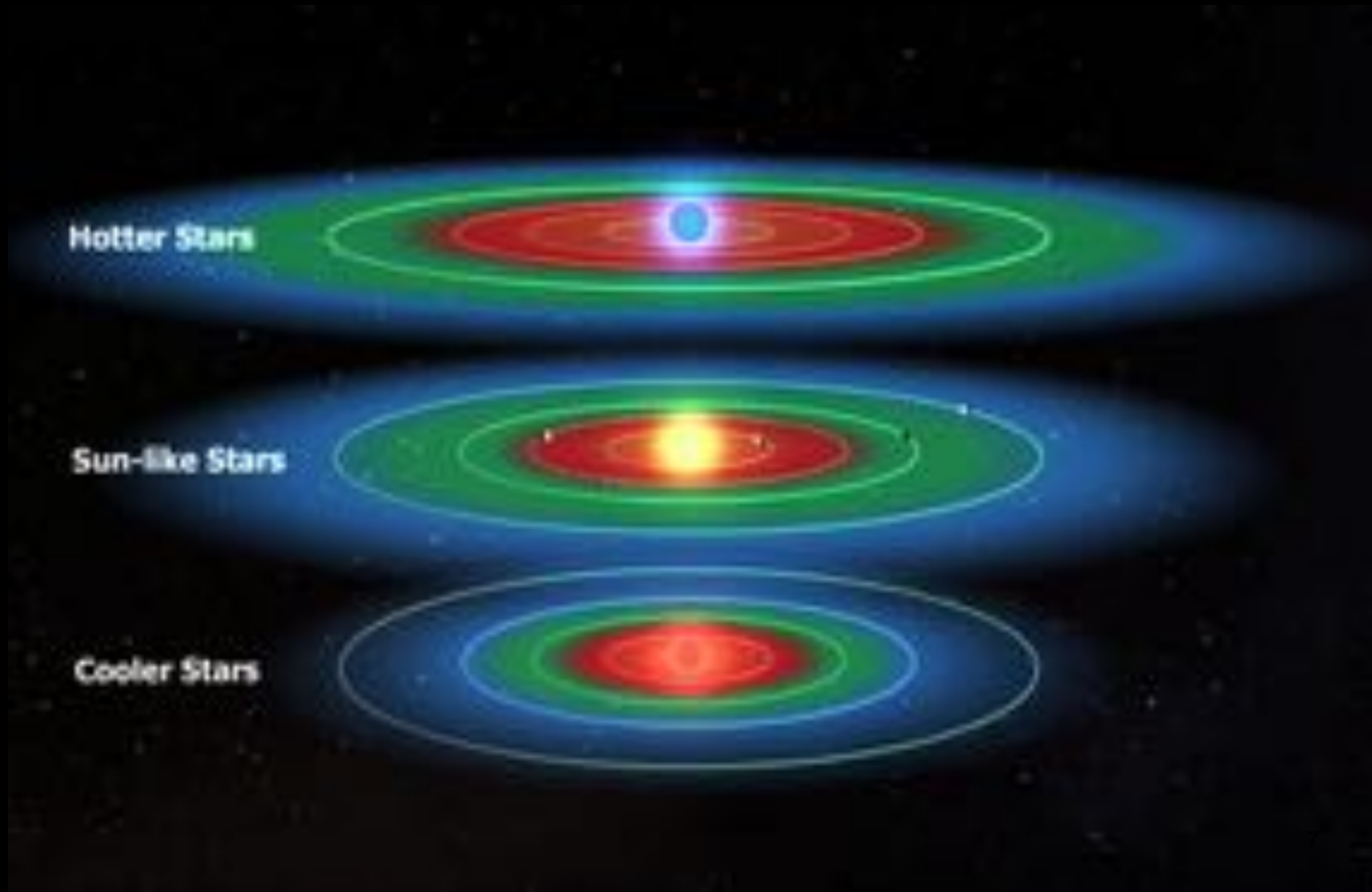


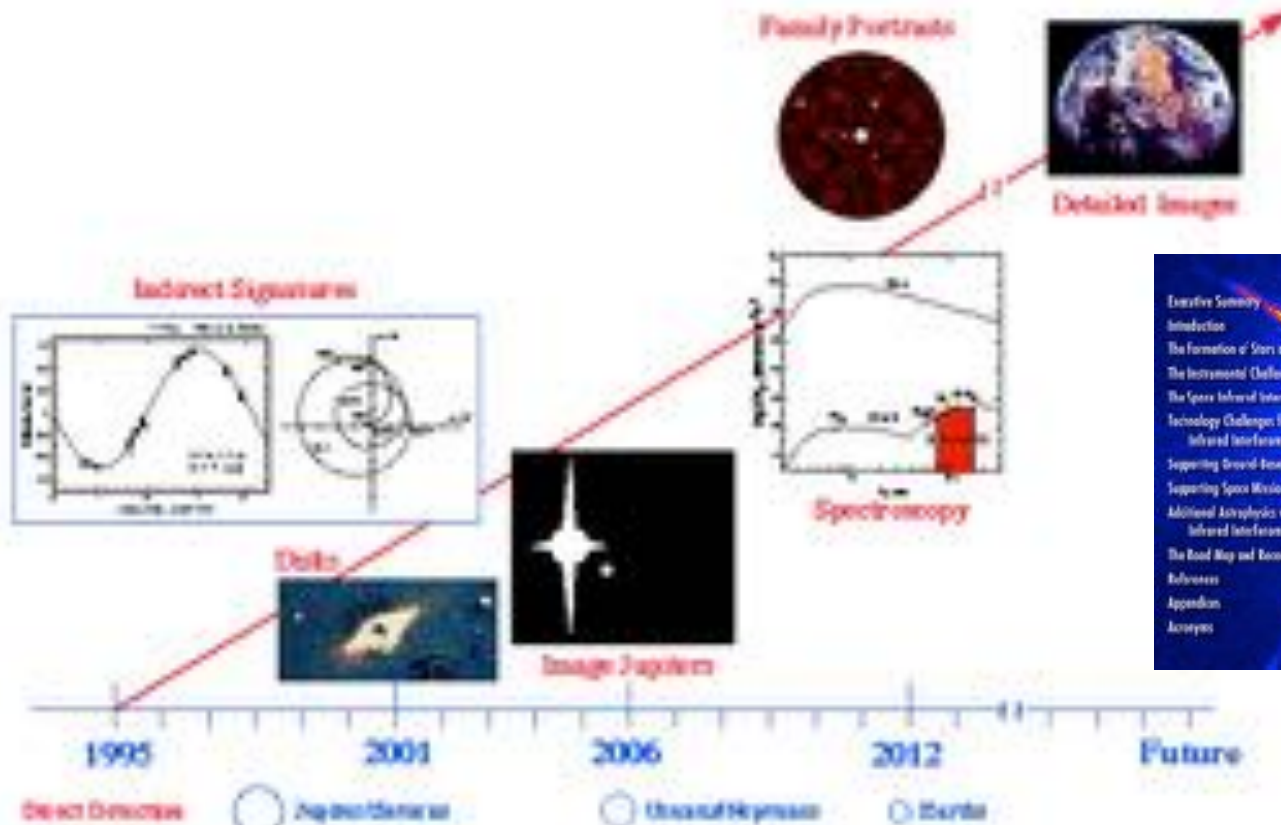
Mars: Way too cold, and small!



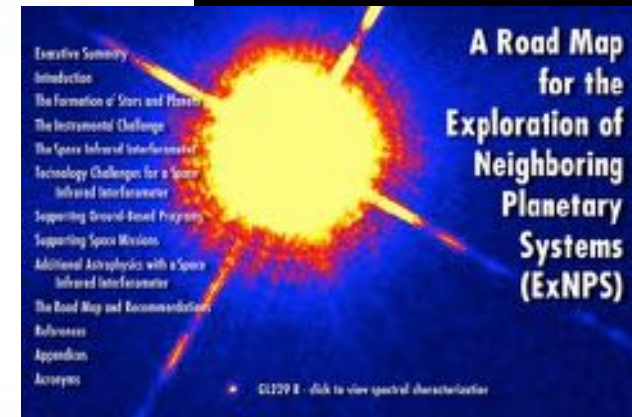
Earth: Just right!

Habitable Zones





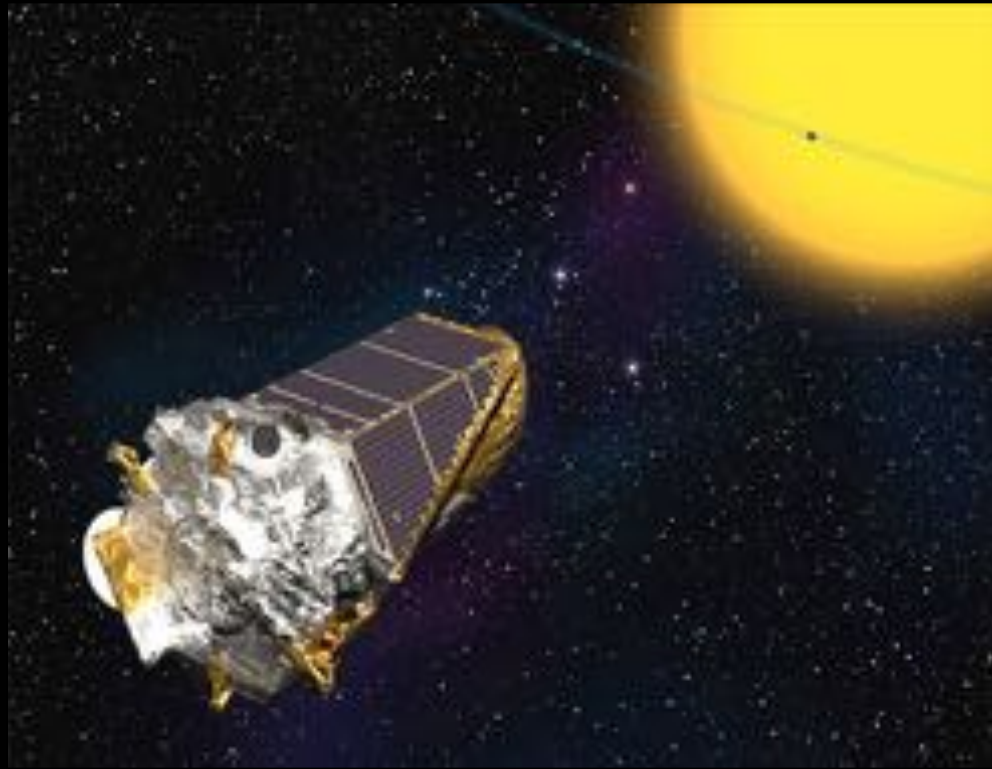
**Transit Photometry
not Recommended!**



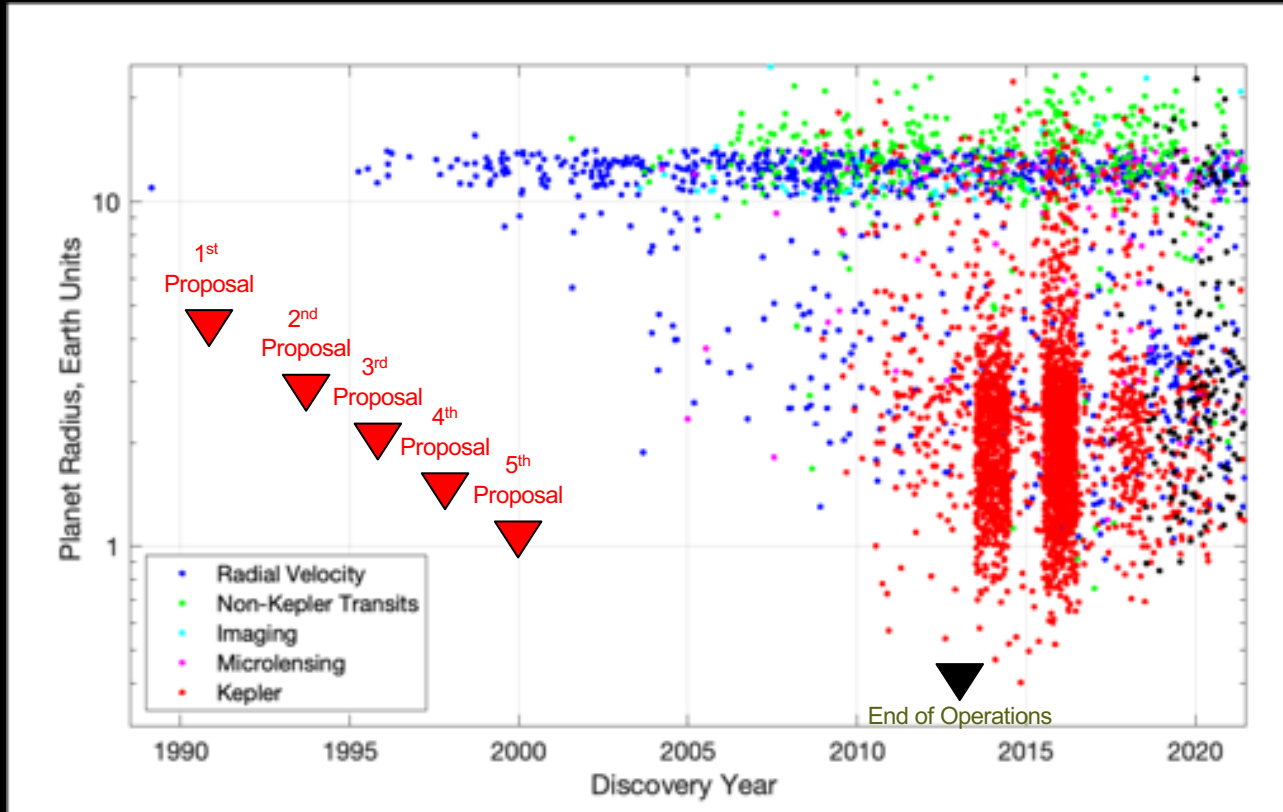
The *Kepler* Mission

How many stars like the Sun have
Earth-like planets orbiting them?

Kepler searches for transiting
planets



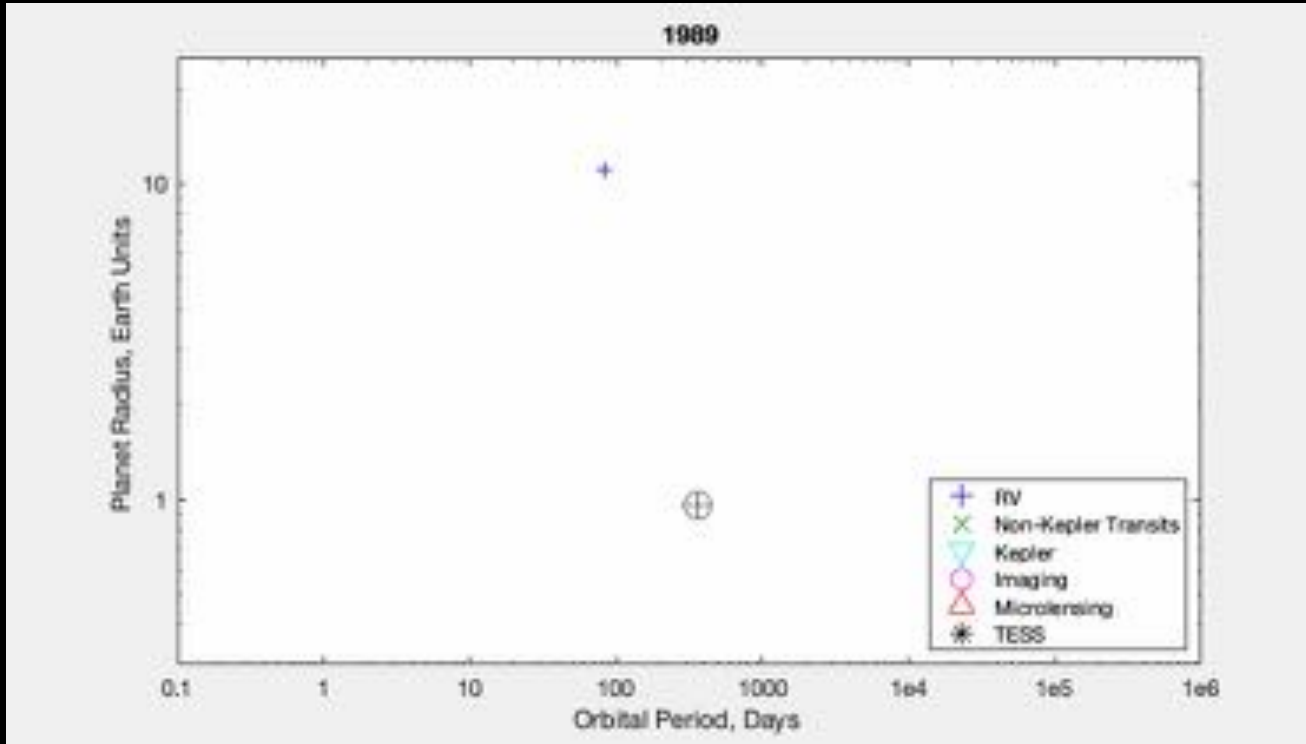
Persistence Pays Off: Exoplanet Discoveries Over Time*



*According to <https://exoplanetarchive.ipac.caltech.edu> as of 10/4/21

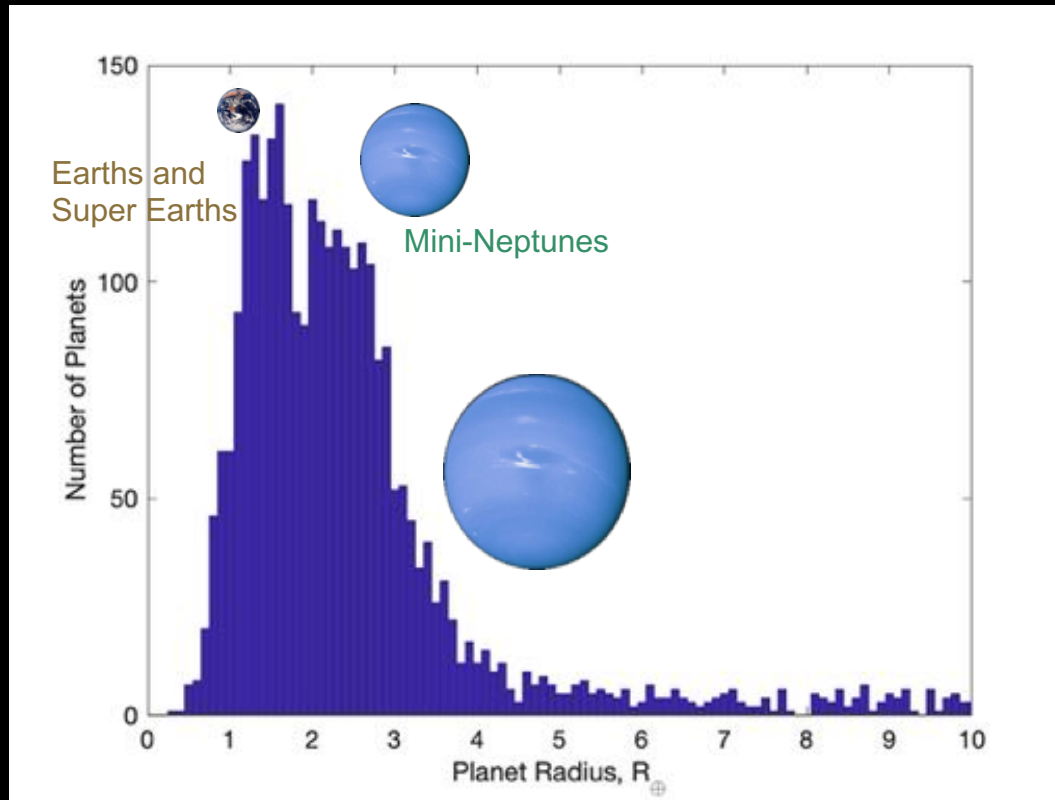
Radii estimated for non-transiting exoplanets
Discovery data dithered slightly

Exoplanet Discoveries



*According to <https://exoplanetarchive.ipac.caltech.edu> as of 10/4/17

The Radius Valley



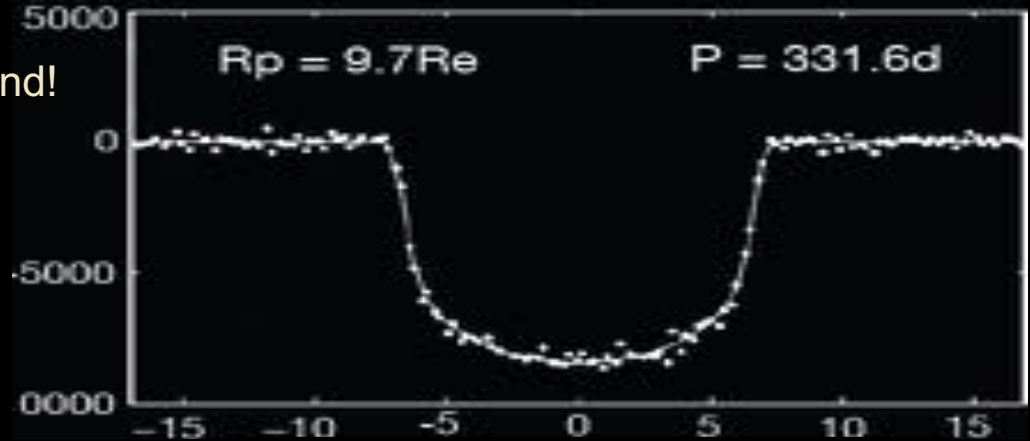
There is a gap between 1.5 and 2 R_{earth} indicating two populations

How Hard is it to Find Good Planets?

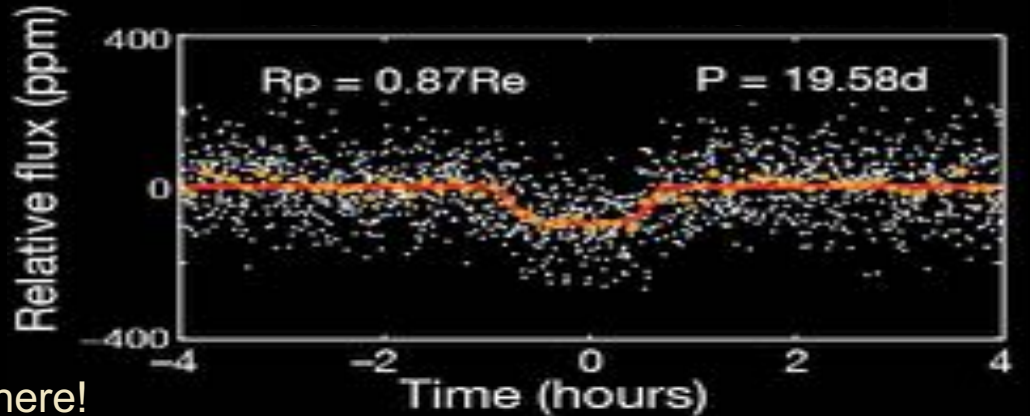


Easy to find from the ground!

Jupiter (~1%)



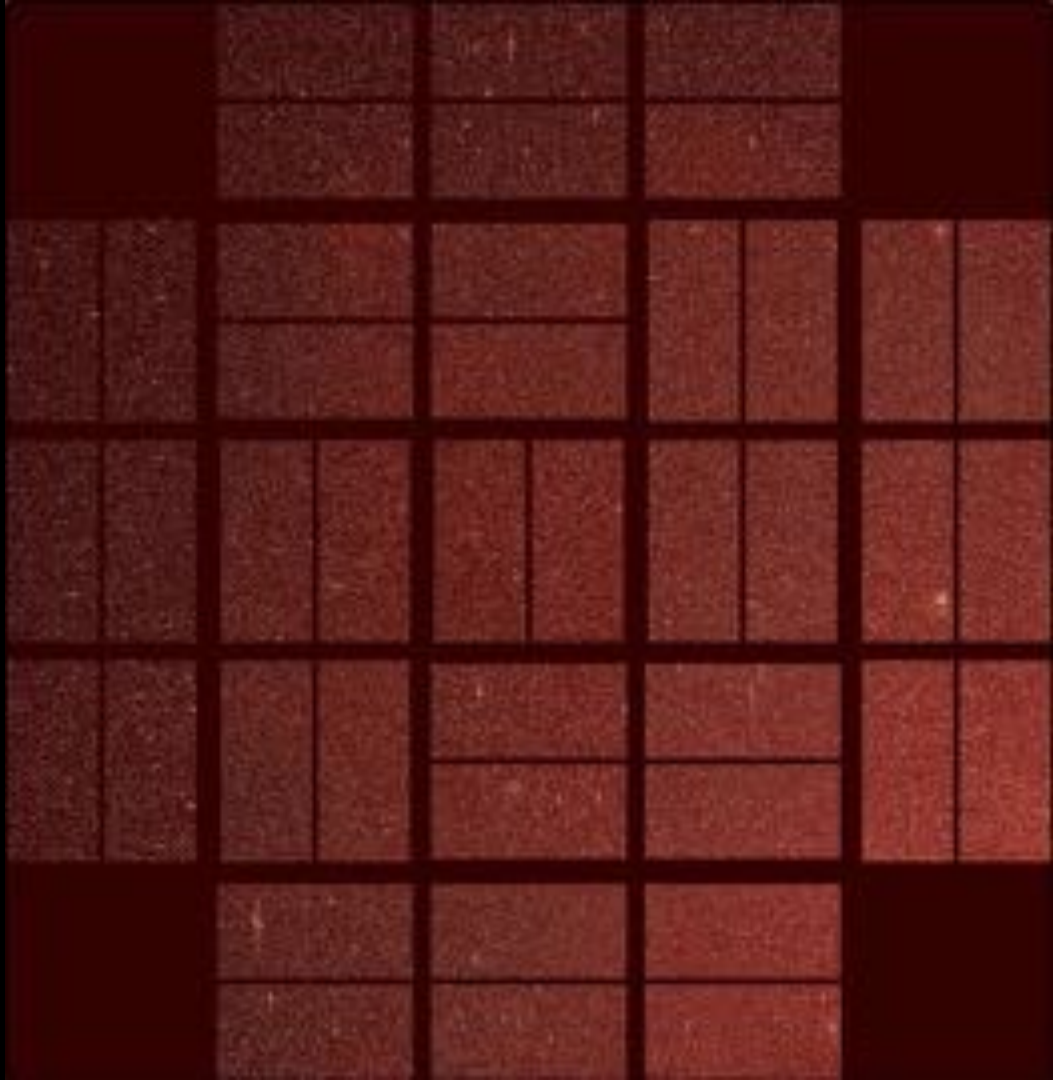
Earth (~0.01%)



Hard to find from anywhere!

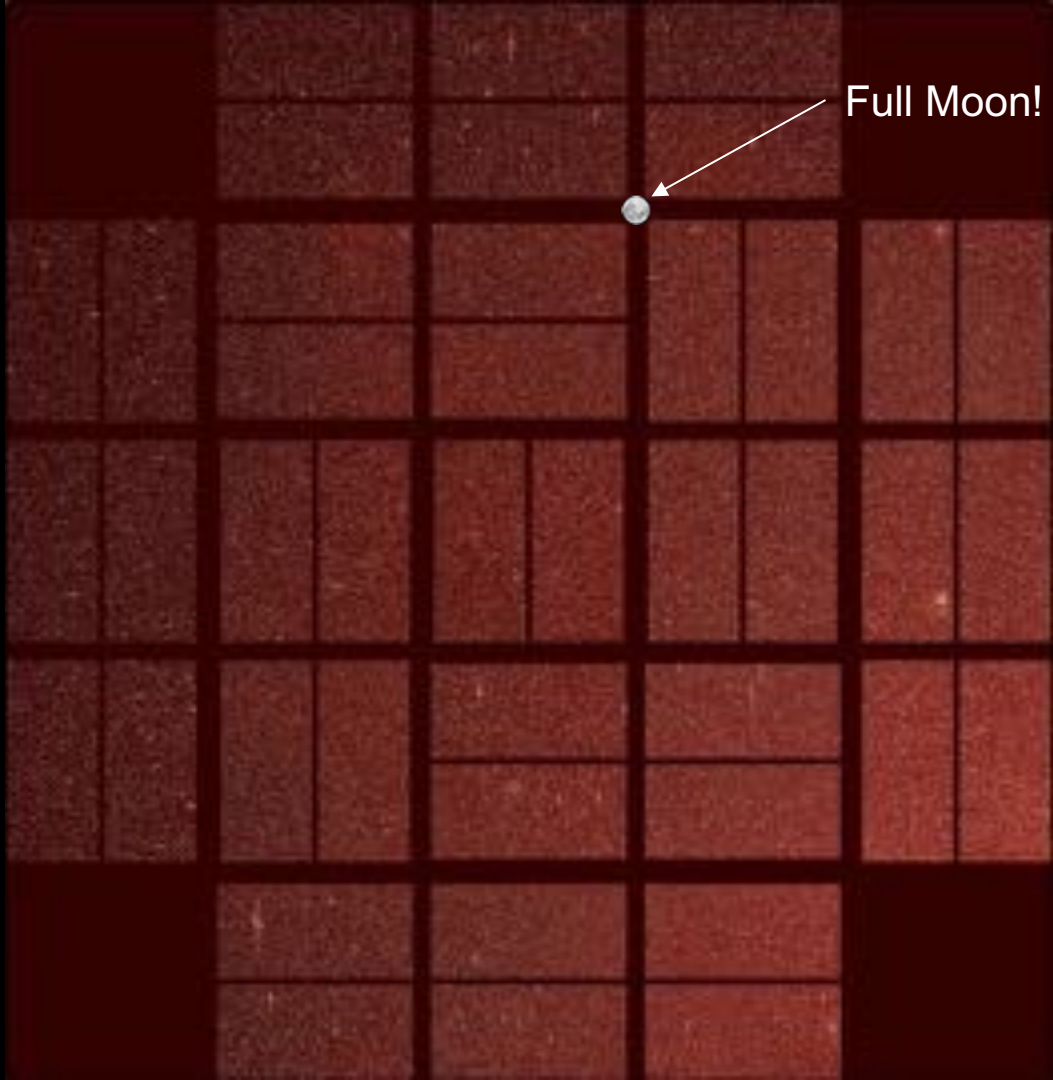
First Light Image

Launched
March 7 2009



First Light Image

Launched
March 7 2009



Full Moon!



Small Rocky Planets



Kepler-20e

Venus

Earth

Kepler-20f



Kepler discovers two Earth-size planets, which scientists believe are rocky, Kepler-20e and Kepler-20f. These two planets are in the Milky Way galaxy, but not in our solar system. Their solar system also contains larger gas giant planets (like Jupiter) in larger orbits.





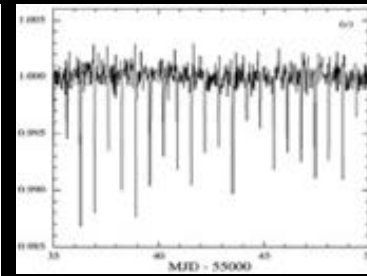
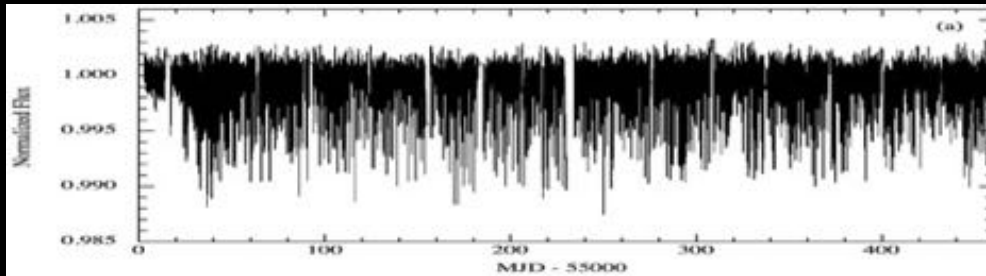
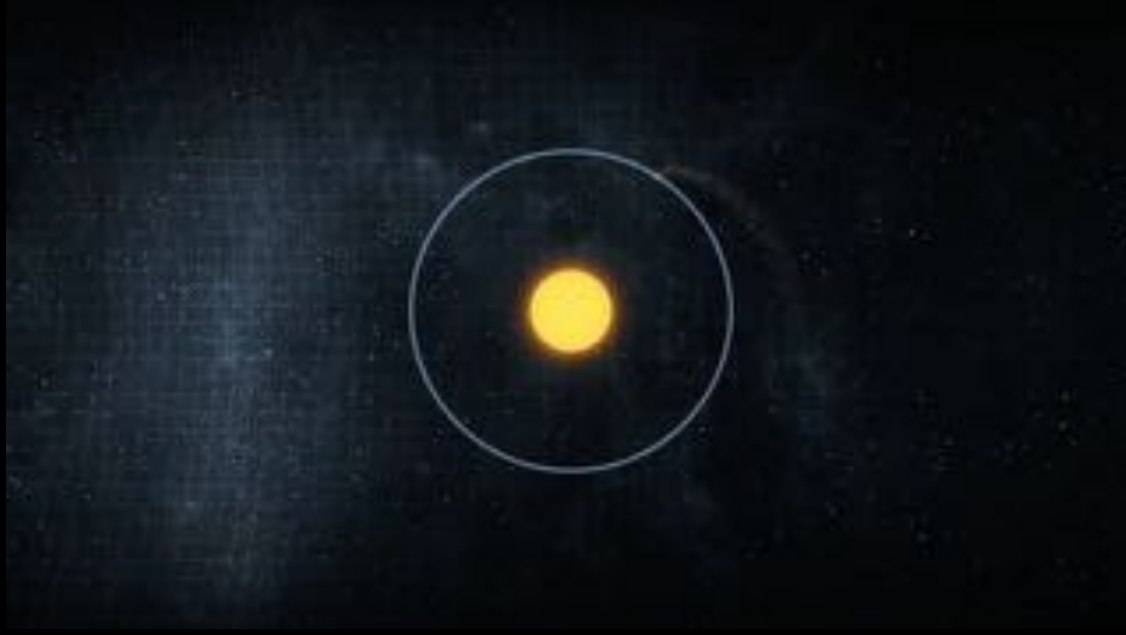
Circumbinary Planets:



Kepler 35

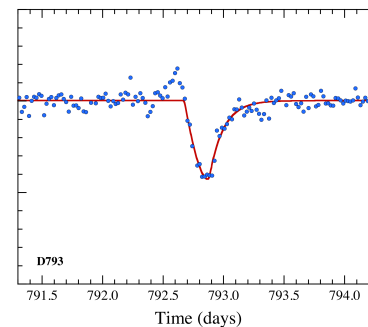
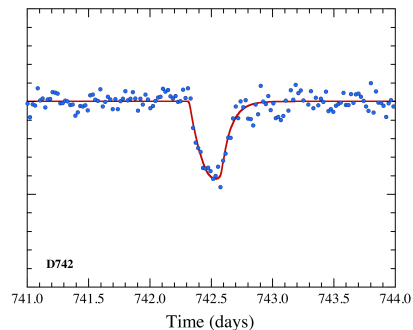
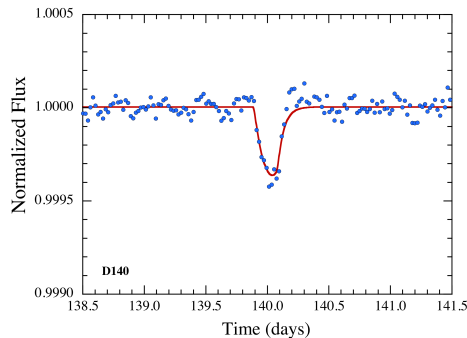
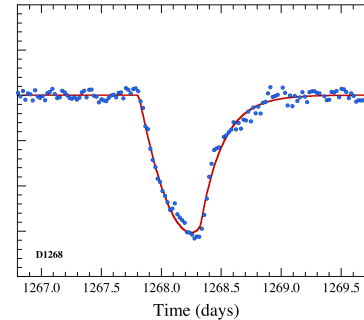
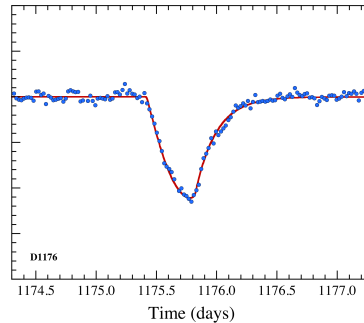
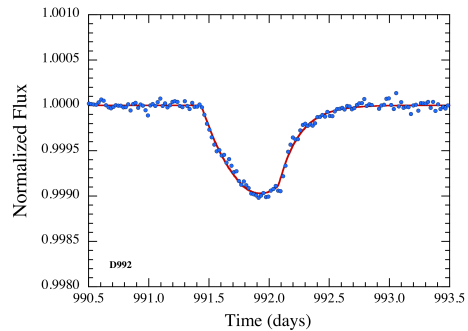


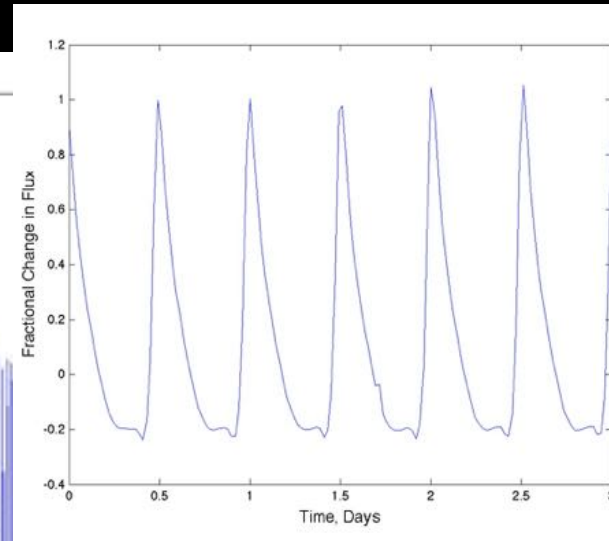
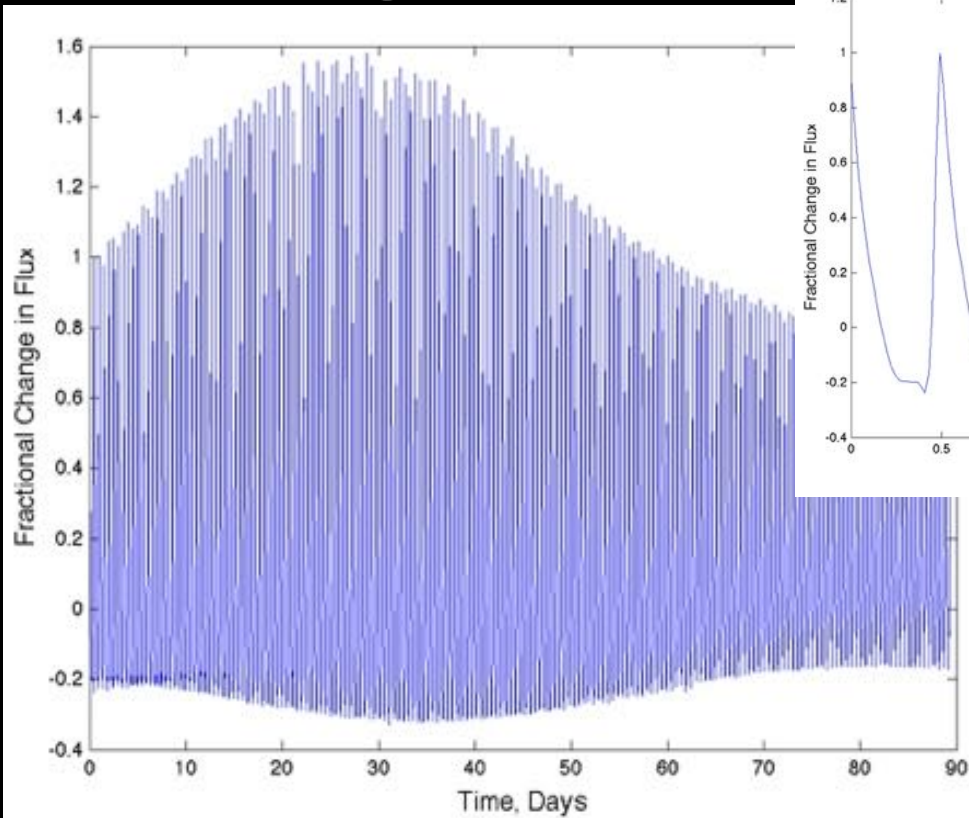
A Disintegrating Sub-Mercury-Size Planet

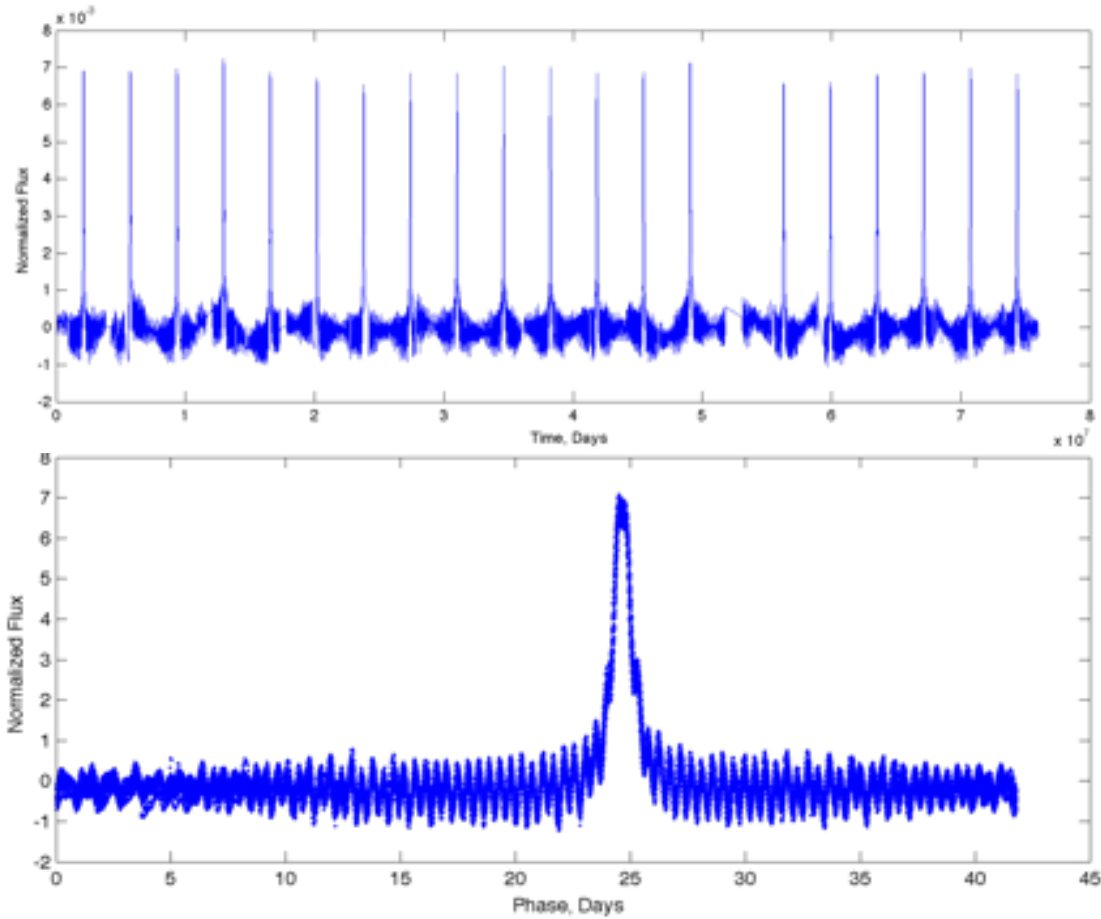




KIC 3542116: An Exocomet Candidate





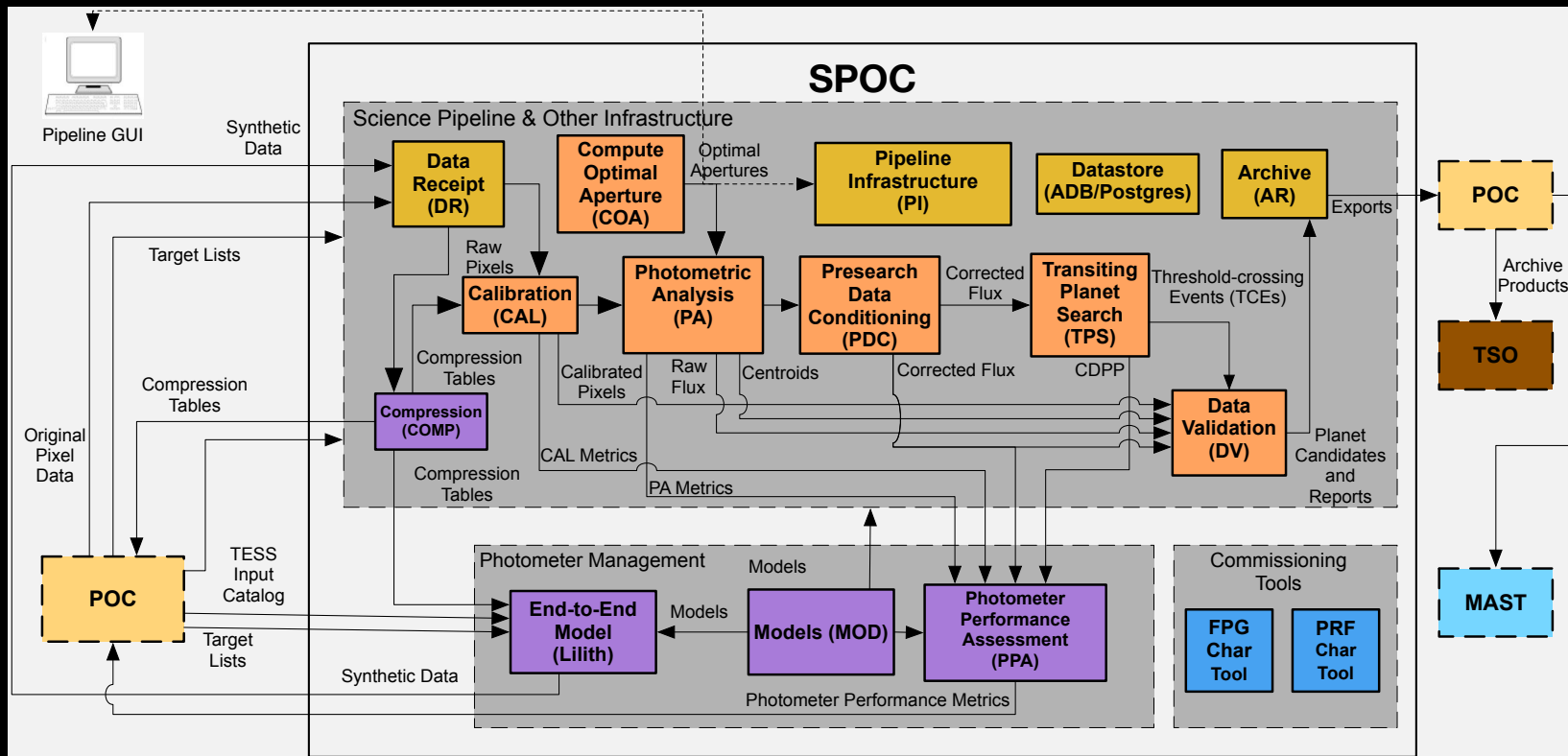


The Kepler Orrery

credit: D. Fabrycky

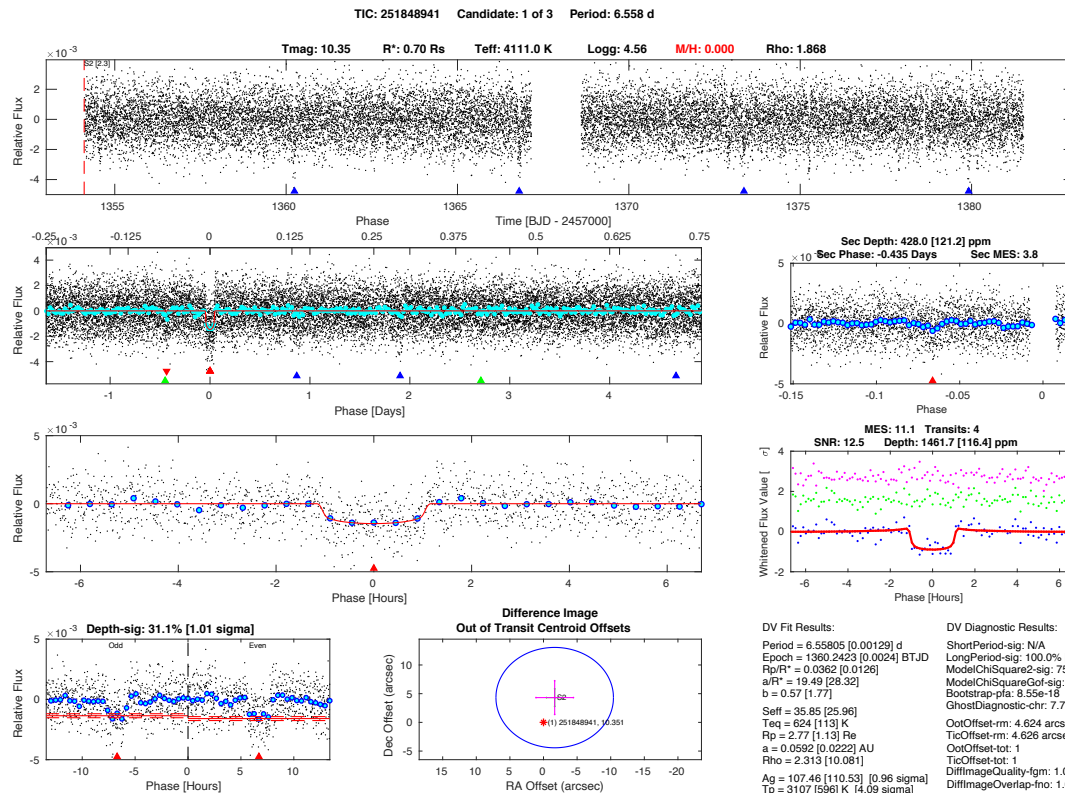
$t[\text{BJD}] = 2454965$







TPS/DV Products



DV Fit Results:

Period = 6.55805 [0.00129] d
Epoch = 1360.2423 [0.0024] BTJD
Rp/R* = 0.0362 [0.0126]
a/R* = 19.49 [28.32]
b = 0.57 [1.77]
Self = 35.85 [25.96]
Teff = 624 [113] K
Rp = 2.77 [1.13] Re
a = 0.0592 [0.0222] AU
Rho = 2.313 [10.081]
Ag = 107.48 [110.53] [0.96 sigma]
Tp = 3107 [586] K [4.08 sigma]

DV Diagnostic Results:

ShortPeriod-sig: N/A
LongPeriod-sig: 100.0% [24.21 sigma]
ModelChiSquare2-sig: 75.6%
ModelChiSquareGof-sig: 100.0%
Bootstrap-pfa: 8.55e-18
GhostDiagnostic-chr: 7.747
OotOffset-rm: 4.624 arcsec [1.59 sigma]
TicOffset-rm: 4.626 arcsec [1.59 sigma]
OotOffset-tot: 1
TicOffset-tot: 1
DiffImageQuality-fgm: 1.00 [1/1]
DiffImageOverlap-fno: 1.00 [1/1]

Software Revision: spoc-3.3.37-20181001 -- Date Generated: 04-Oct-2018 16:01:30 Z

This Data Validation Report Summary was produced in the TESS Science Processing Operations Center Pipeline at NASA Ames Research Center



Kepler taught us that planets are everywhere!

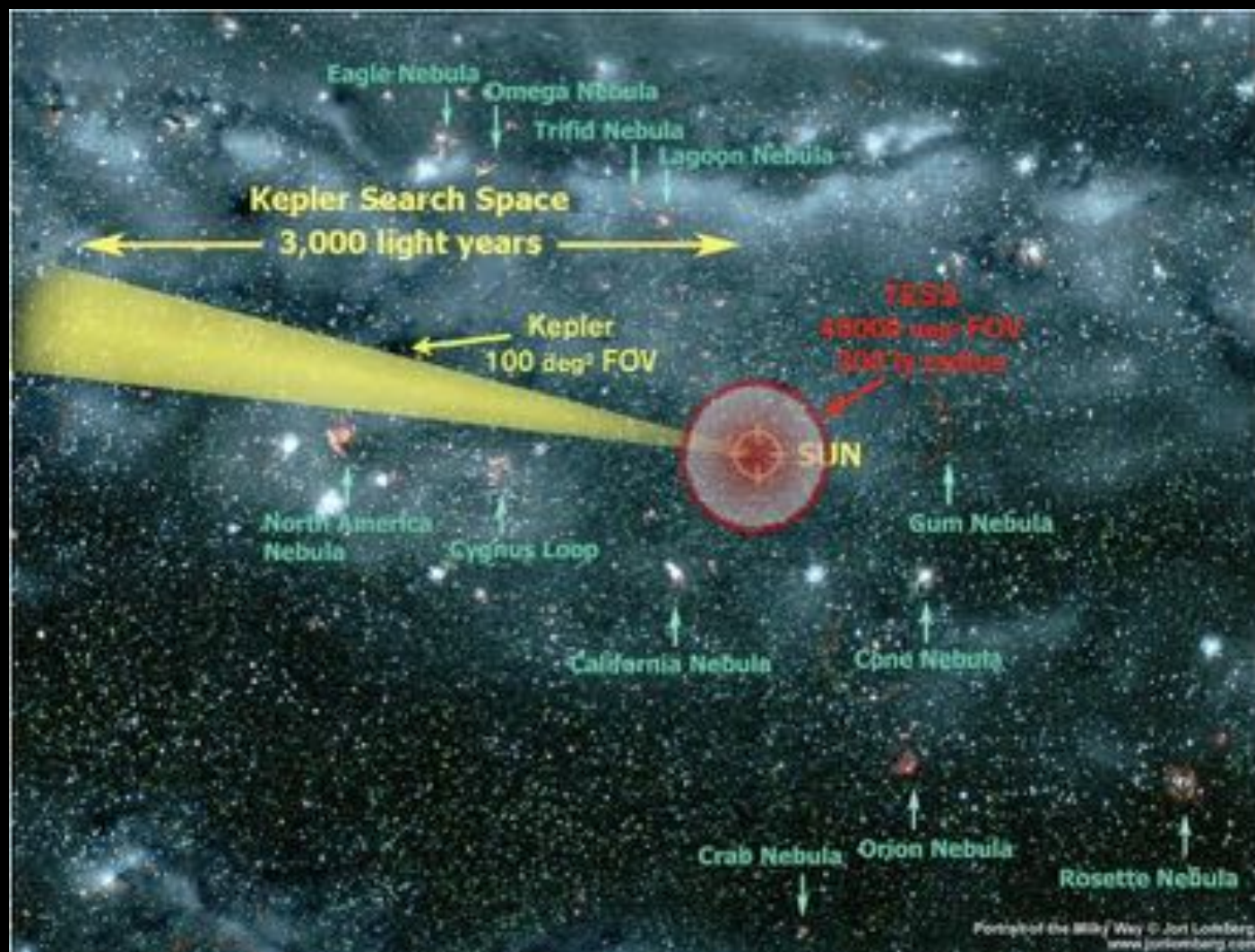
What Next?



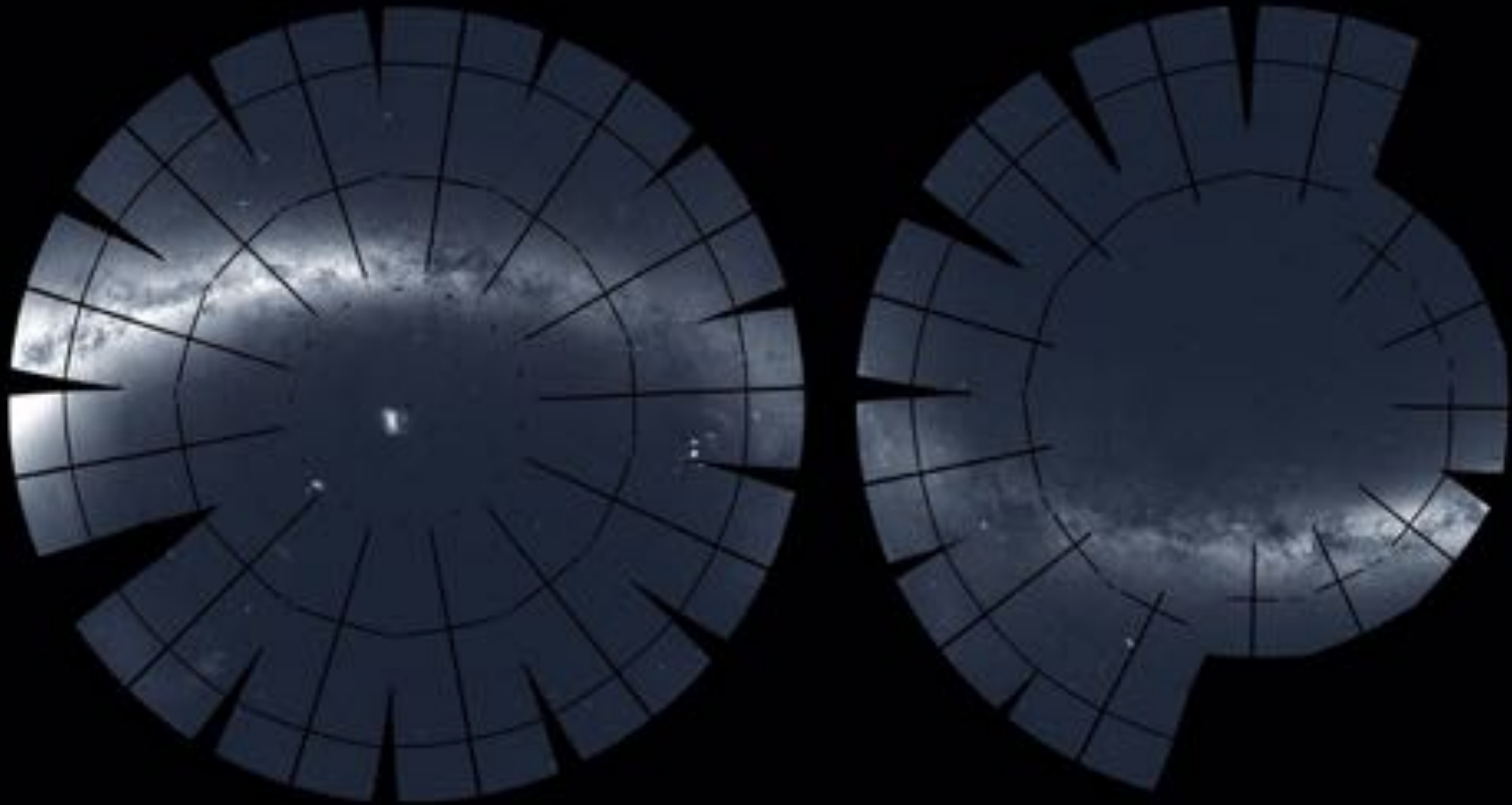
TRANSITING EXOPLANET SURVEY SATELLITE

*DISCOVERING NEW EARTHS AND SUPER-EARTHS
IN THE SOLAR NEIGHBORHOOD*

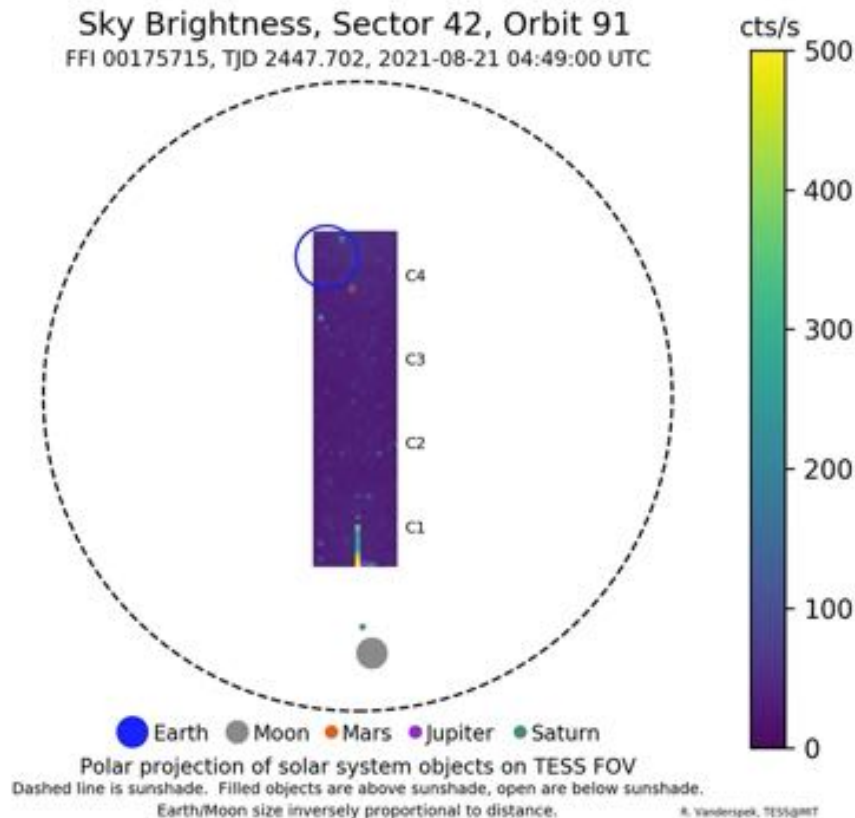




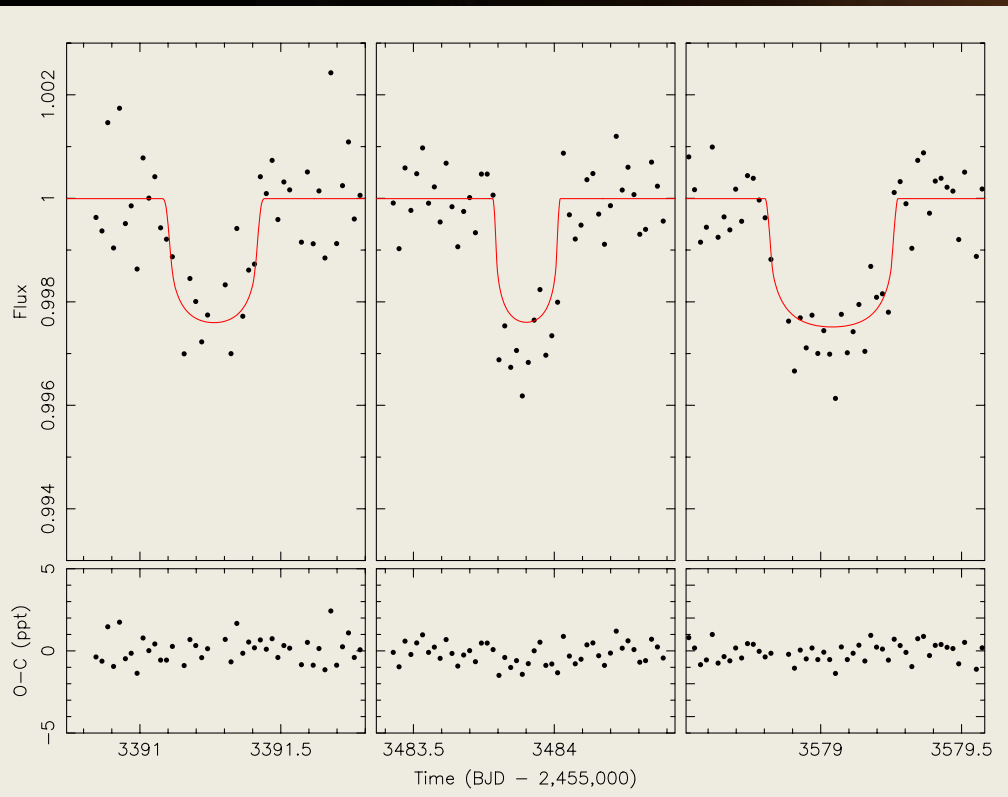
TESS Primary Mission Sky Coverage



Observing from TESS is Interesting!

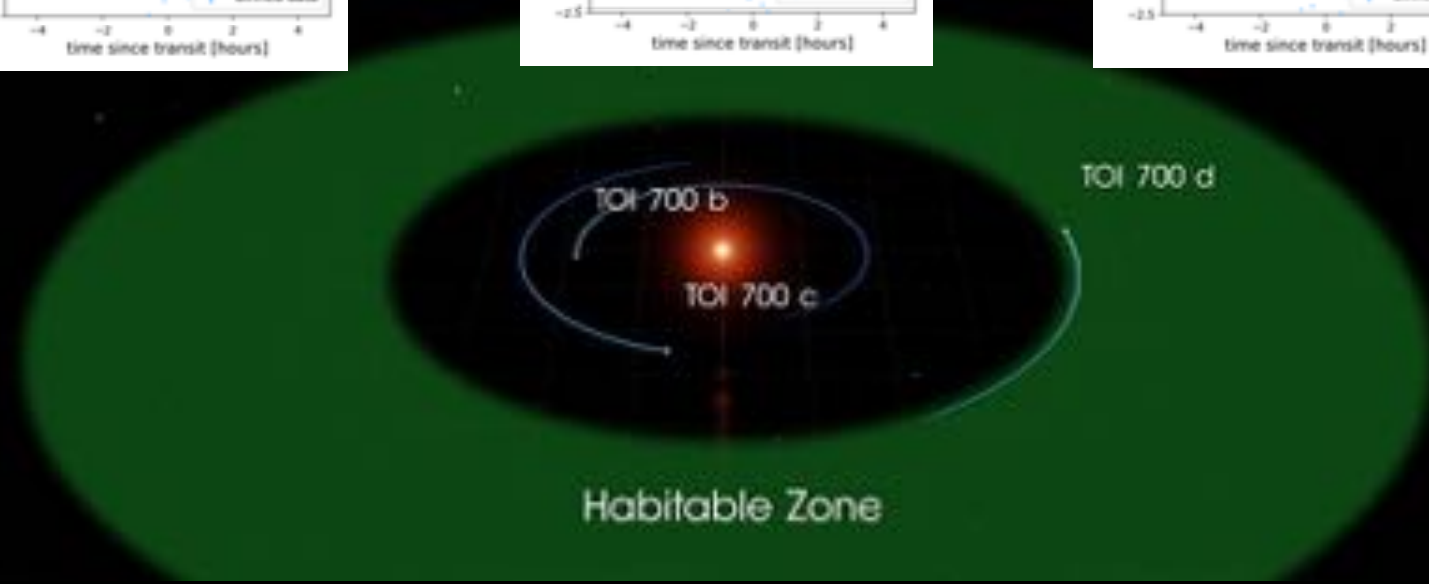
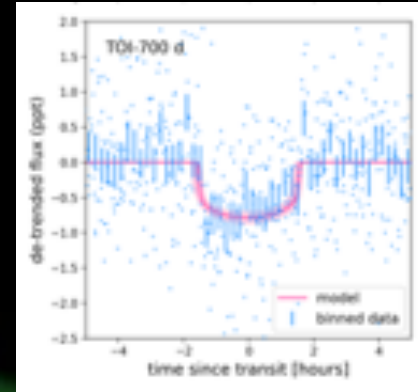
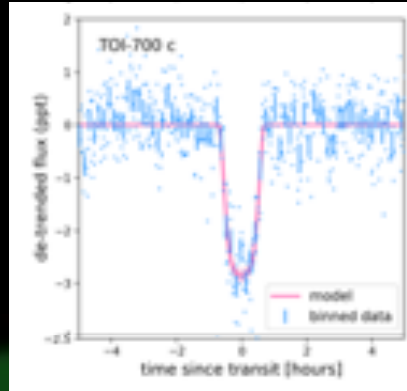
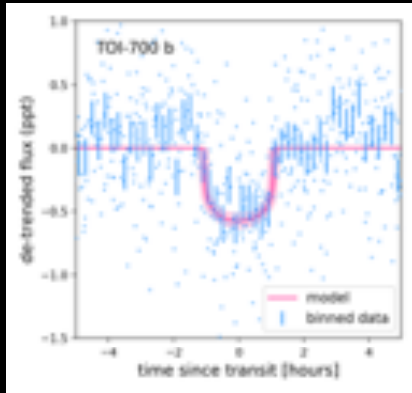


First Circumbinary Planet: TOI-1338b

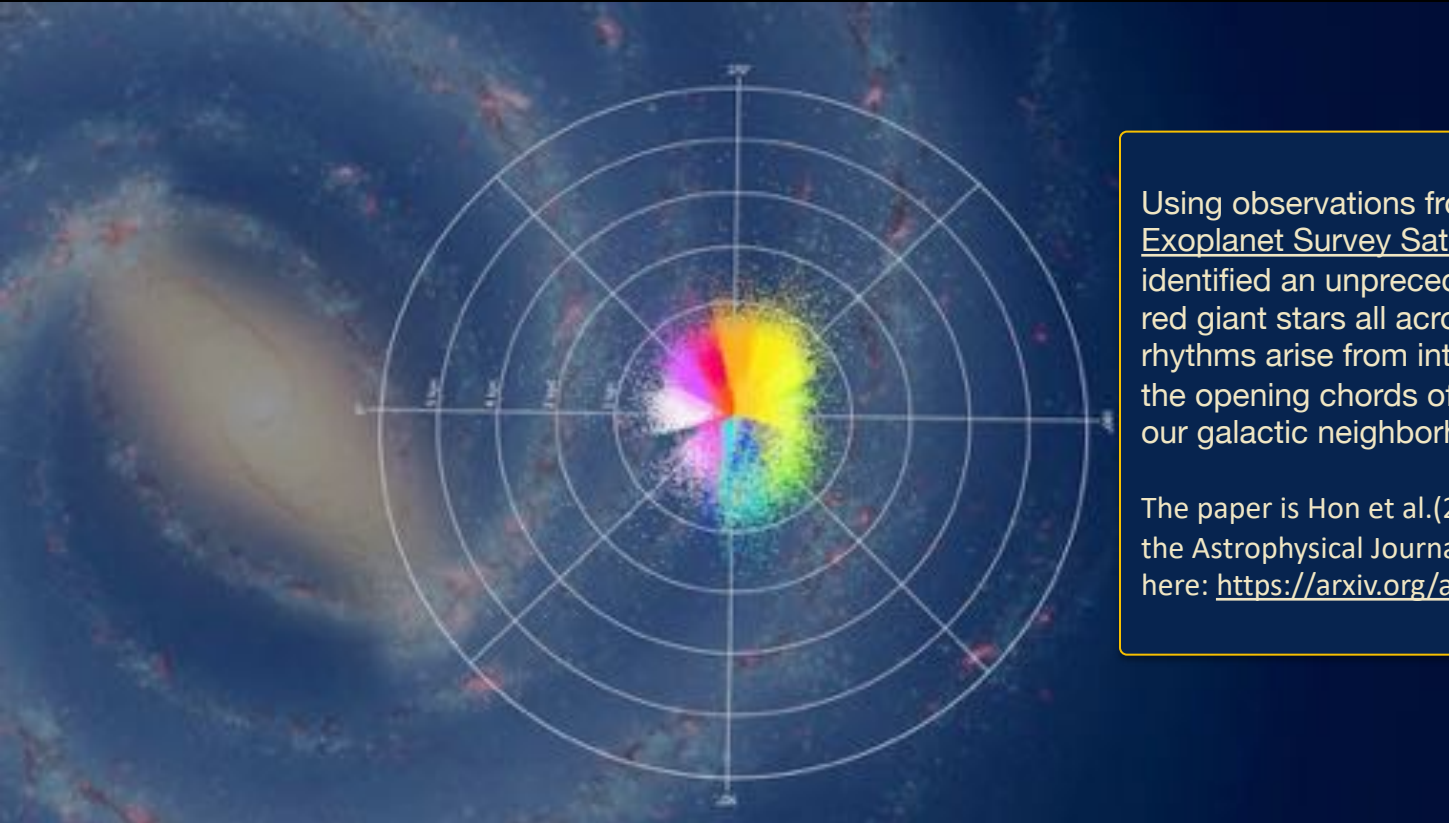




TESS's First Earth-Sized Habitable Zone Planet: TOI-700d



A Symphony of Red Giants across the Sky



Using observations from NASA's Transiting Exoplanet Survey Satellite (TESS), astronomers have identified an unprecedented collection of pulsating red giant stars all across the sky. These stars, whose rhythms arise from internal sound waves, provide the opening chords of a symphonic exploration of our galactic neighborhood.

The paper is Hon et al.(2021) and has been accepted by the Astrophysical Journal, and is available on astro-ph here: <https://arxiv.org/abs/2108.01241>.

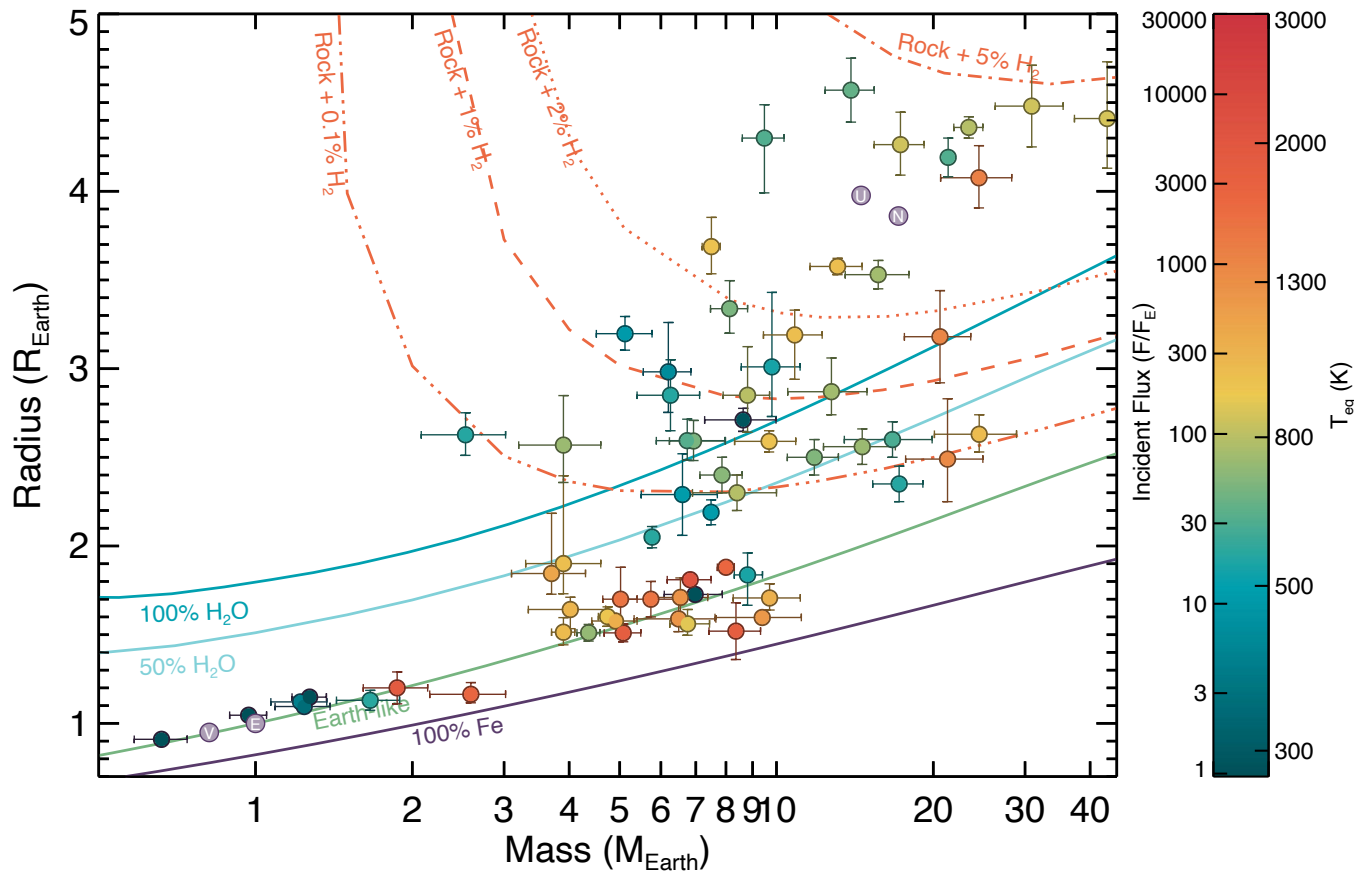


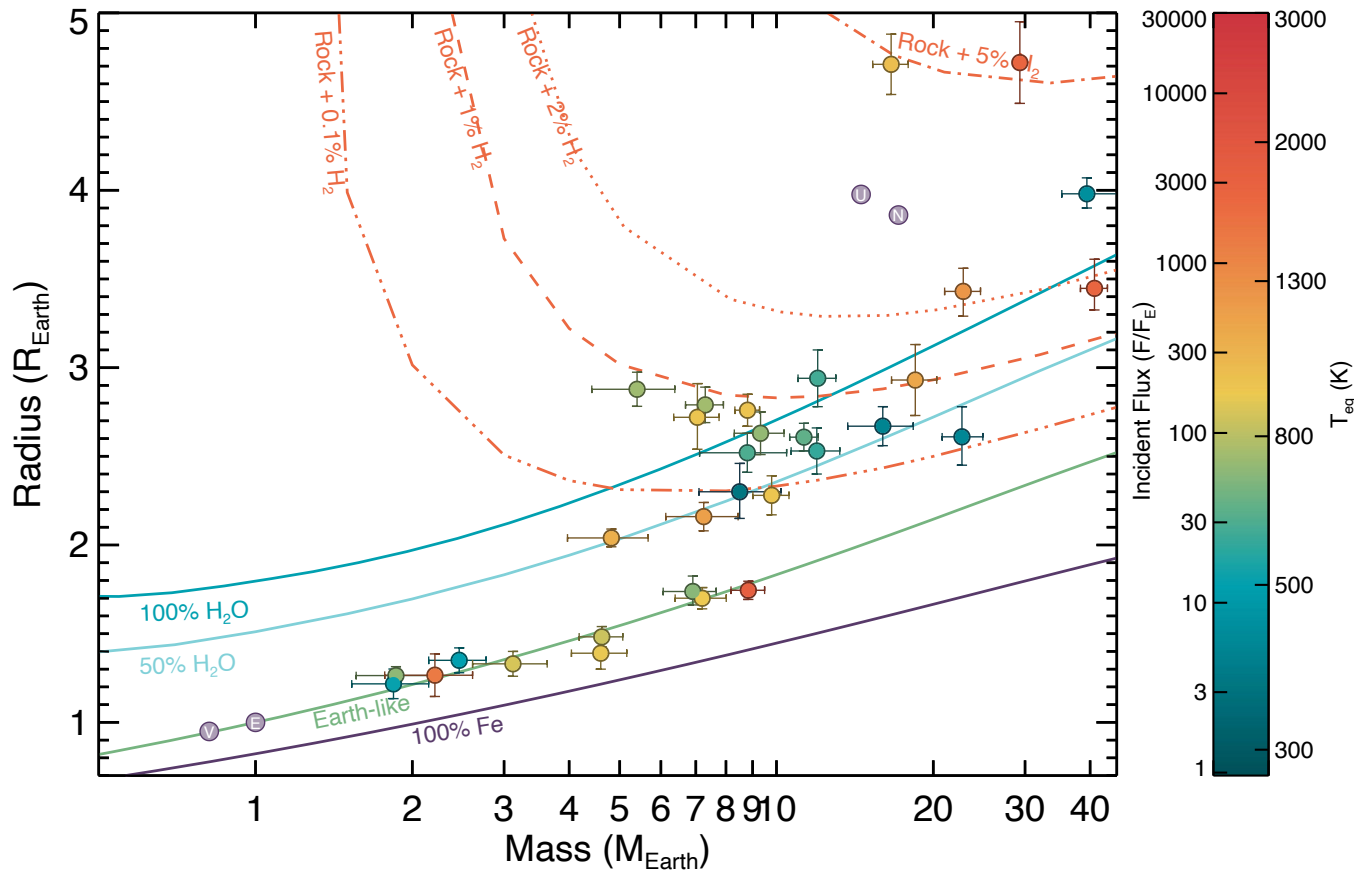
Draco

74 Draconis
5.5 times the Sun's size

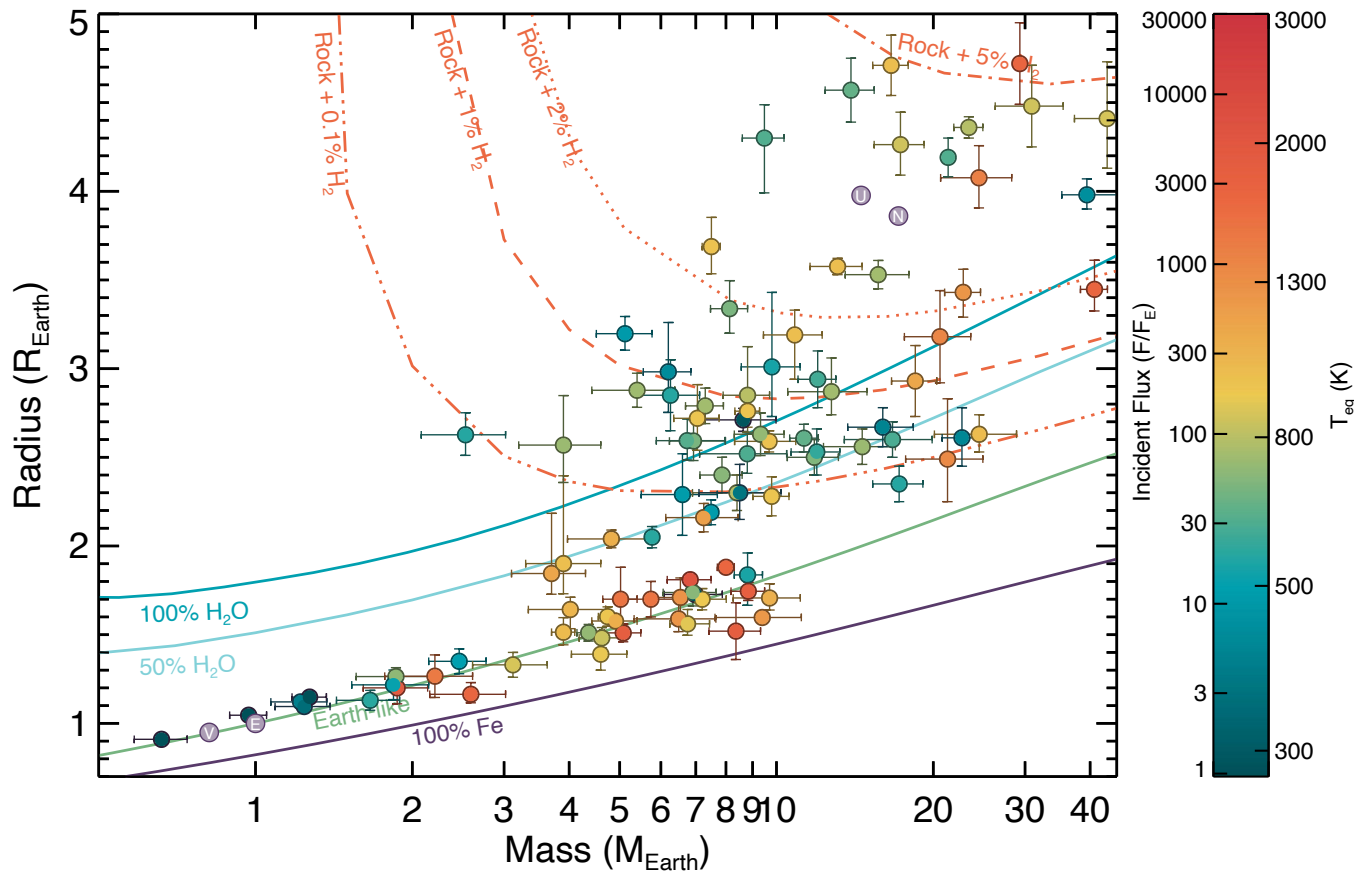
Credit: NASA/MIT/TESS and Ethan Kruse (USRA), M. Hon et al., 2021

Mass Determinations Before TESS



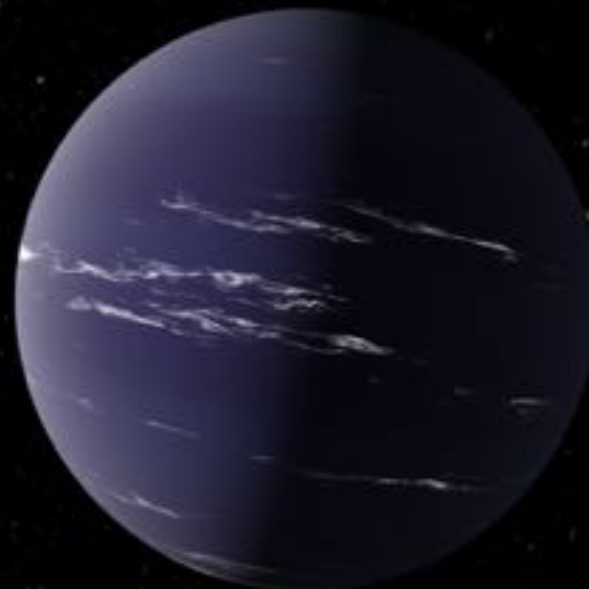
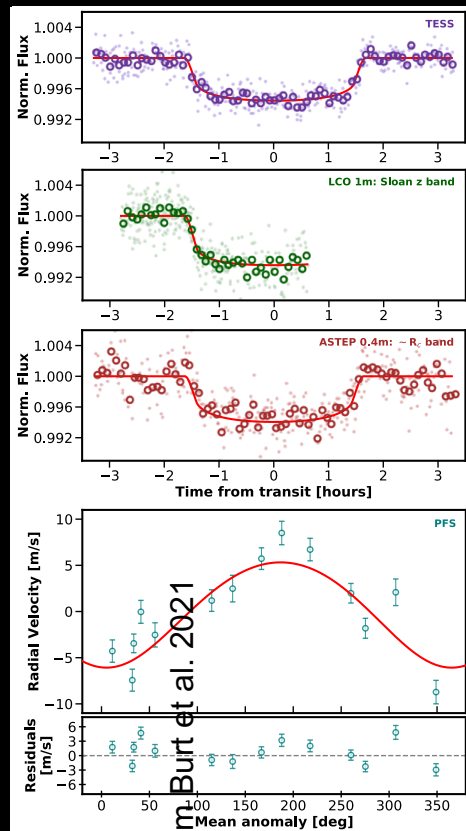


Mass Determinations with TESS

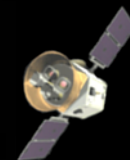


A Temperate Neptune-Sized Planet Orbiting Nearby Dwarf NLTT 24399 only 27.5 pc Away

$R_p = 3.65 R_e$, $T_p = 24.246$ days, $M_p = 15.5 M_e$, $T_{eq} = 330$ K



We may be able to detect atmospheric escape via Doppler velocity observations



An exciting target for JWST!



JWST Cycle 1 Transiting Exoplanet Targets from TESS

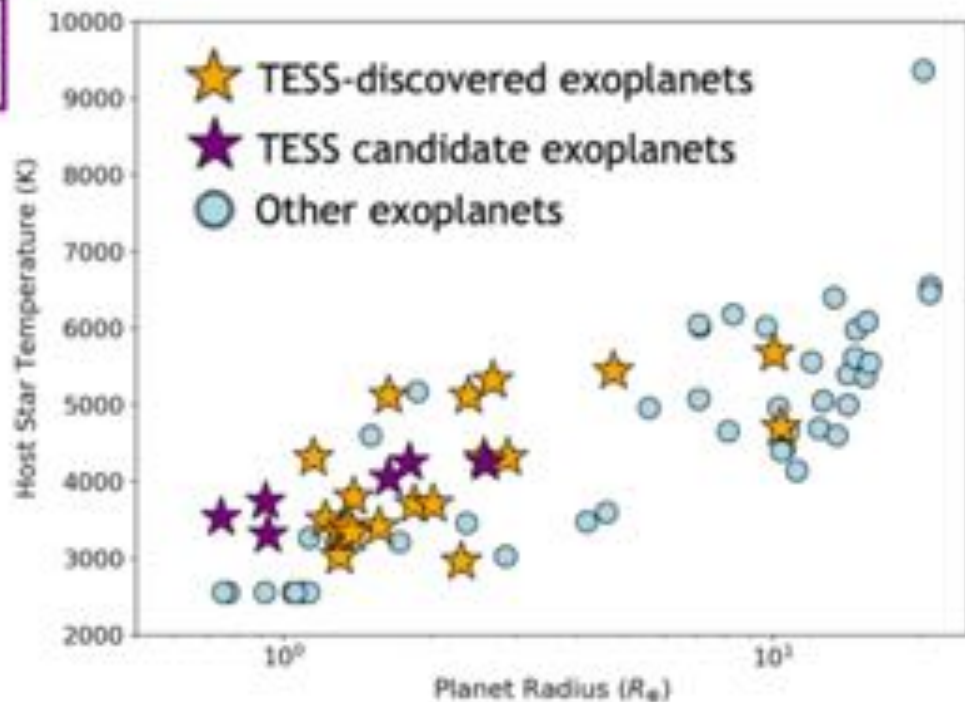
A majority of the TESS exoplanets to be observed by JWST are small (< 3 Earth radii) and orbit small, cool stars.

Confirmed TESS Planets on the JWST Cycle 1 List

GJ 357 b	LTT 1445 A b
GJ 486 b	LTT 9779 b
HD 15337 b	TOI 178 b
HD 15337 c	TOI 178 d
HIP 67522 b	TOI 178 g
L 168-9 b	TOI 421 b
L 98-59 c	TOI 776 b
L 98-59 d	TOI 776 c
LHS 3844 b	W 1856 b
LP 791-18 c	

Candidate TESS Planets on the JWST Cycle 1 List

TOI 260.01
TOI 731.01
TOI 741.01
TOI 836.01
TOI 836.02
TOI 910.01



Detecting Biomarkers through Transit Spectroscopy

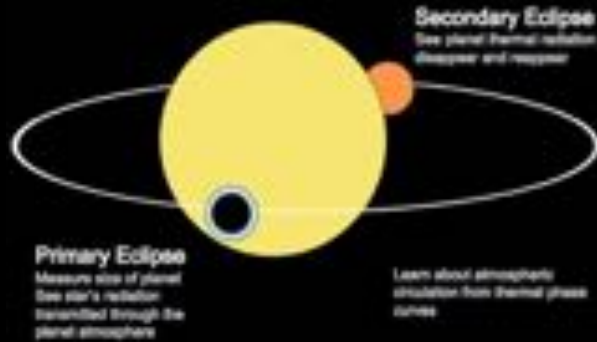
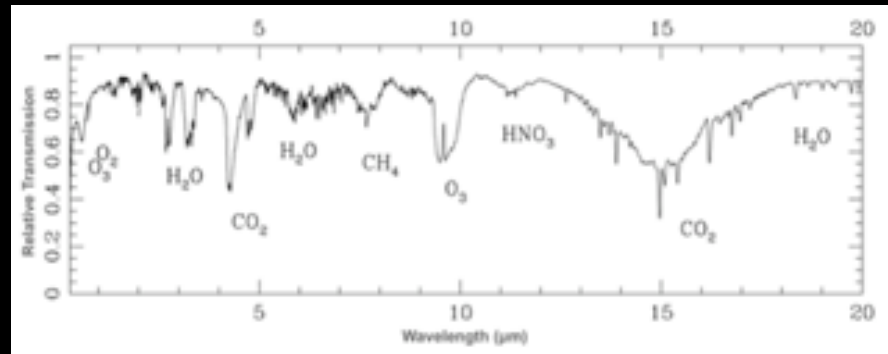


Figure by S. Seager



Kaltenegger, L. and Traub, W. (2009) Transits of Earth-Like Planets, ApJ

Exoplanet Missions



¹ NASA/ESA Partnership

² NASA/ESA/CSA Partnership

³ CNES/ESA

Ground Telescopes with NASA participation

What can you do to help study exoplanets?

Do you like Science?

Do you like Math?

Do you like Art?

We need:

- Scientists
- Astronomers
- Engineers
- Data Scientists
- Mathematicians
- Software Engineers
- Artists
- Managers



Do you have questions?

